KOMATIITES FROM THE COMMONDALE GREENSTONE BELT, SOUTH AFRICA: A POTENTIAL ANALOG TO IONIAN ULTRAMAFICS? D.A. Williams[1], A.H. Wilson[2], R. Greeley[1], [1]Department of Geology, Arizona State University, Box 871404, Tempe, Arizona, 85287 (dwilliams@dione.la.asu.edu), [2]Department of Geology, University of Natal, Durban, 4041, SOUTH AFRICA.

Introduction: Recent observations of Jupiter's volcanic moon Io by the Galileo Solid State Imaging (SSI) system have indicated that at least 12 vents may be erupting lavas much hotter than those found on terrestrial volcanoes, with eruption temperatures >1700-2000 K (~1430-1730°C) [1]. These temperatures are consistent with terrestrial Precambrian komatiitic lavas [2]. However, preliminary spectral analysis of the Galileo SSI data indicates the presence of magnesium-rich orthopyroxene (opx) in the Ionian ultramafics [1], in contrast to terrestrial komatiites in which the dominant phenocryst phases are either olivine or clinopyroxene and opx is absent. The apparent presence of opx in the Ionian ultramafics would tend to rule out most komatiites as useful terrestrial analogs to these lavas. However, researchers at the University of Natal have found an unusual, 3.3 Ga komatiite in the Commondale greenstone belt of South Africa that contains opx-spinifex phenocrysts and which may have been derived from a very high MgO liquid. Thus, we propose that this komatiite may be a useful terrestrial analog for the high-temperature ultramafics that may be erupting on Io.

Background: Komatiites are the metamorphosed remnants of ancient ultramafic lava flows, and are found almost exclusively in Precambrian terrains [2]. They are noted for their high MgO contents (~18-30%), low dynamic viscosities (~0.1 Pa·s), high liquidus temperatures (~1600°C), and great potential for turbulent flow and thermal erosion of their underlying substrates. Whereas most interest in komatiites has been in understanding their relationship to associated sulfide ore deposits [3], komatiites are of interest to planetary geologists primarily as an analog to low-viscosity extraterrestrial lavas such as lunar basalts, and as a terrestrial example of the potential of thermal erosion to produce large (10s-100s km long, 10s m deep) lava channels, which some believe is the process responsible for the formation of some extraterrestrial lava channels [4,5,6].

While there is considerable variation in the thicknesses and extents of komatiite flows, they are somewhat limited in terms of composition and texture. Komatiite lavas range in thickness from a few cm (e.g., Pyke Hill, Munro Township, Ontario [7]) to 10s of meters (e.g., Kambalda, Western Australia [8]). Individual flows tend to have some combination of aphyric, spinifex, and cumulate zones [7] consisting of olivine and/or clinopyroxene phenocrysts, with spinel (chromite) as an accessory phase. The great extents (~10s m thick, ~10s to 100s km long) of some Western Australian komatiites led to the suggestion that these komatiites may have produced large flow fields akin to the lunar maria or continental flood basalts [9].

The Commondale Komatiites: The Commondale greenstone belt (~3.2-3.5 Ga, [10, 11]) is located ~120 km south of the Barberton greenstone belt in South Africa. The komatiitic sequence at Commondale is ~1.5 km thick and is composed of several hundred flow units. The morphology of individual komatiite flow units includes (top to bottom) a thin chilled flow top, a spinifex zone consisting of exclusively opx or opx with platy olivine, a mixed olivine cumulate zone (which also contains 2-10% opx spinifex) that grades downward into cumulus olivine, a basal olivine cumulate, and a lower chill zone. Individual flow units at Commondale range from 1-13 m thick, although most flows are typically 1-3 m thick. The opx spinifex is characteristic of the whole sequence at Commondale, and to the best of our knowledge this is the only komatiite locality in the world bearing opx spinifex. The olivines are up to Fo_{93}, and the orthopyroxenes are up to En_{94}, indicative of crystallization from very Mg-rich liquids.

Physical Properties: Based on the chemical composition inferred for the Commondale komatiites, we have used several algorithms from experimental petrology (summarized in [12]) to calculate the thermal and rheological properties of these lavas relative to other komatiites and basalts (Table 1). From these properties, it is possible to calculate (for a given flow thickness) the flow velocity, Reynolds number, Prandtl number, and convective heat transfer coefficient for the Commondale komatiites and compare these properties to those of other terrestrial komatiites (Table 1). An estimate of the thermal erosion rate of basaltic substrate can also be made.

Results: As indicated in Table 1, the higher MgO content of the Commondale komatiites results in a liquidus (and potentially eruption) temperature about 50°C hotter than typical Barberton/Munro komatiites, and the higher SiO_2 and lower FeO contents result in a lower liquid density than other terrestrial komatiites. Presumably the higher SiO_2, higher MgO, and lower FeO contents are also responsible for the production of opx as a primary crystallization phase. The Reynolds numbers for the Commondale komatiites suggest flows should have erupted turbulently, based on the flow thicknesses observed in drill core, similar to most other terrestrial komatiites. However, the convective heat transfer coefficient is somewhat lower than that of other terrestrial komatiites, probably also due to the atypical composition of the Commondale komatiites. This indicates that the thermal erosion potential of the Commondale komatiites was less than that of other terrestrial komatiites, and thus that these lavas were less capable of forming thermal erosion channels in the substrate.

Discussion: If a high temperature, opx-bearing ultramafic composition continues to be the best interpretation of Galileo multispectral data for the hottest Ionian lavas, then it may be possible to use the Commondale komatiite as an analog for further physical/geochemical modeling of the inferred Ionian ultramafics. For example, it should be possible to adapt existing models for the thermal/rheological/fluid dynamic/geochemical evolution of terrestrial komatiites [12] to investigate the emplacement of Ionian ultramafic lavas. Hopefully, if high resolution Galileo images can be obtained of recent high-temperature Ionian flows during orbits I24 or I25 (Oct.-Nov., 1999), these data may help to constrain some modeling parameters such as eruption temperature, flow rate or composition. Further work is in progress.

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Table 1. Inferred liquid compositions and corresponding physical properties for several komatiitic and basaltic lavas.

Component	Commondale Komatiite	Barberton Komatiite	Munro Komatiite	Cape Smith Kom. Basalt	Lunar Mare Basalt	Tholeiitic Basalt
SiO_2	49.8	47.9	46.8	46.9	43.6	50.9
TiO_2	0.1	0.4	0.4	0.6	2.6	1.7
Al_2O_3	7.9	4.1	7.7	9.8	7.9	14.6
Fe_2O_3	0.5	1.9	-	-	-	-
FeO	4.8	9.7	10.5	14.4	21.7	14.6
MnO	0.1	0.2	0.2	0.3	0.3	-
MgO	30.9	27.5	25.2	18.9	14.9	4.8
CaO	5.2	7.5	7.5	8.6	8.3	8.7
Na_2O	0.4	0.2	0.01	0.3	0.2	3.1
K_2O	0.01	0.02	0.01	0.05	0.05	0.8
T_{liq} (°C)	1611	1556	1528	1419	1440	1160
T_{sol} (°C)	1170	1170	1170	1150	1150	1080
ρ @ T_{liq} (kg/m^3)	2680	2760	2760	2800	2920	2730
c (J/kg·°C)	1780	1740	1720	1640	1573	1470
μ @ T_{liq} (Pa·s)	0.22	0.20	0.30	0.81	0.75	86
L @ T_{liq} (J/kg)	6.84E+05	6.58E+05	6.46E+05	5.96E+05	5.65E+05	5.37E+05
k @ T_{liq} (J/m·s·°C)	0.04	0.08	0.1	0.3	0.3	4.4
h (m)	10	10	10	10	10	10
u @ T_{liq} (m/s)	4.6	4.6	4.4	4.0	4.2	2.2
Re @ T_{liq} (-)	5.71E+05	6.51E+05	4.23E+05	1.44E+05	3.05E+05	7.29E+02
Pr @ T_{liq} (-)	8.81E+03	4.41E+03	4.85E+03	4.05E+03	2.49E+03	2.93E+04
h_T @ T_{liq} (J/m^2·s·°C)	47	71	73	102	116	N/a
u_{mb} @ T_{liq} (m/day)	0.40	0.55	0.53	0.56	0.68	N/a
Composition Location	Commondale, South Africa	Barberton, South Africa	Mickel, Abitibi GSB Canada	Katinniq, Cape Smith Belt, Canada	Apollo 12 Sample 12002	CRB, Washington
Composition Reference	This Study	[13]	[14]	[15]	[16]	[17]

Symbols: T_{liq} = Liquidus temperature, T_{sol} = solidus temperature, ρ = lava density, c = specific heat, μ = dynamic viscosity, L = heat of fusion, k = thermal conductivity, h = flow thickness, u = flow velocity, Re = Reynolds #, Pr = Prandtl #, h_T = convective heat transfer coefficient, u_{mb} = thermal erosion rate of consolidated basalt, GSB = greenstone belt, N/a = not applicable for non-turbulent flows.